Vertical Distribution of Soil Moisture As A Control on Respiration in Dryland Ecosystems

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1. Introduction

Total ecosystem respiration (Reco) incorporates both autotrophic (Ra) and heterotrophic (Rh) components of respiration, which may respond differently to various environmental controls. Typically, soil temperature is considered the dominant control on soil respiration. However, in semi-arid ecosystems, soil moisture is also a key driver.

Many recent studies have investigated this soil moisture control on respiration, yet none have considered how the temporal and spatial variability in the vertical distribution of that soil moisture influences soil respiration. In pulse-driven semiarid ecosystems, considering the vertical distribution of soil moisture is critical: frequent small pulses of precipitation wet only the surface soil, while infrequent and less-predictable large pulses of precipitation wet the deeper soil layers.

The spatial extent of drylands (over 30% of the land surface is arid or semi-arid) suggest that changes in their carbon flux behavior may strongly impact global climate patterns.

2. Hypotheses

Here we examine several hypotheses, using a Q10-type exponential relationship between respiration and temperature.

1--Among several environmental variables (soil temperature, season, vegetation type, and soil moisture) temperature and soil moisture are the major factors affecting respiration.

2--The soil moisture control on respiration acts as a threshold response, not a continuous response.
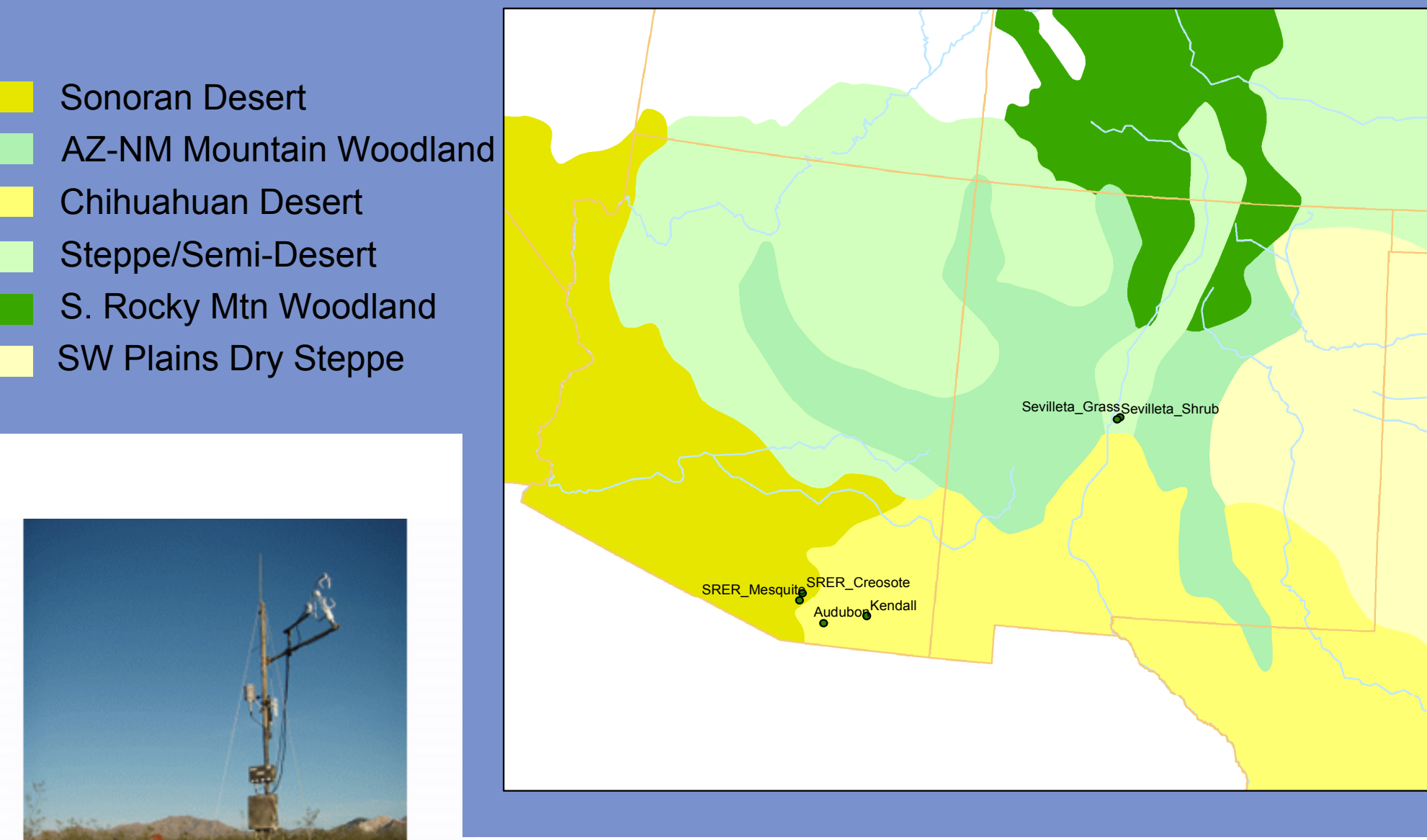
3--Variability in the vertical distribution of soil moisture will alter the pattern of soil respiration in these ecosystems (Kurc and Small 2007).

These hypotheses were tested using data from five Ameriflux sites located in the southwestern US (two grasslands, two shrublands and one savannah).
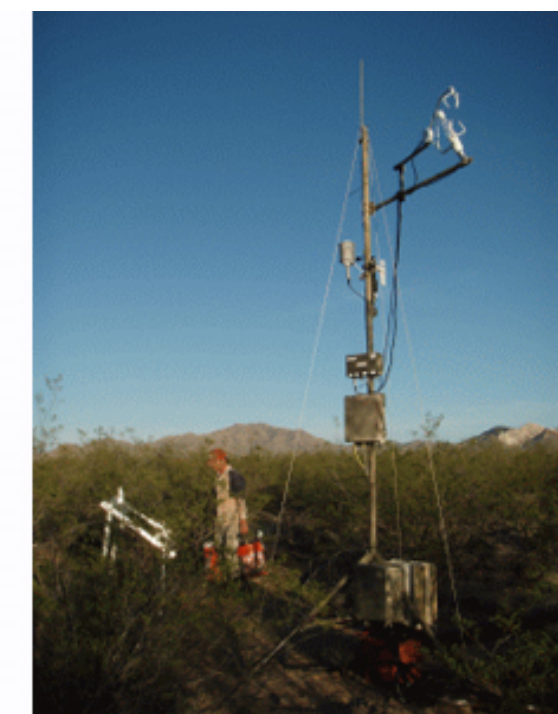
3. Flux Measurement Sites

Site	Research Unit	Vegetation Type	Mean Precip (mm)	Mean Temp (°C)	Length of Record (yrs)
Sevilleta Grass	Sevilleta LTER	Grassland	250	17.7	3 (2002-2004)
Sevilleta Shrub		Grassland			3 (2002-2004)
Kendall Grass	Walnut Gulch Exp. Watershed	Grassland	357	17	4 (2004-2007)
SRER Mesquite	Santa Rita Experimental Range	Woody Savanna	310	19.1	4 (2004-2007)
SRER Creosote		Open Shrubland			
Audubon Grass	Appleton-Whittell Research Ranch	Grassland	350	15.96	4 (2002-2005)
Niwot Ridge	Niwot Ridge LTER	Evergreen needleleaf forest	800	1.5	4 (2004-2007)

Summary data for Ameriflux sites used in this study

- Sonoran Desert
- AZ-NM Mountain Woodland
- Chihuahuan Desert
- Steppe/Semi-Desert
- S. Rocky Mtn Woodland
- SW Plains Dry Steppe

Map of flux tower sites

Tower at SRER Creosote

4. Why a Q_{10} type relationship?

A Q_{10}-type relationship, where Reco = f(Tsoil) provides several benefits:

- a continuous function (vs. the categorical variables tested here)
- ease of interpretation when comparing performance on categorical variables
- simple parameter estimation procedure
- ready comparison to other studies which apply similar models.

Here, we use a model of the form:
$$Reco = ae^{bTsoil}$$
and report parameter values and variance explained for each fit.
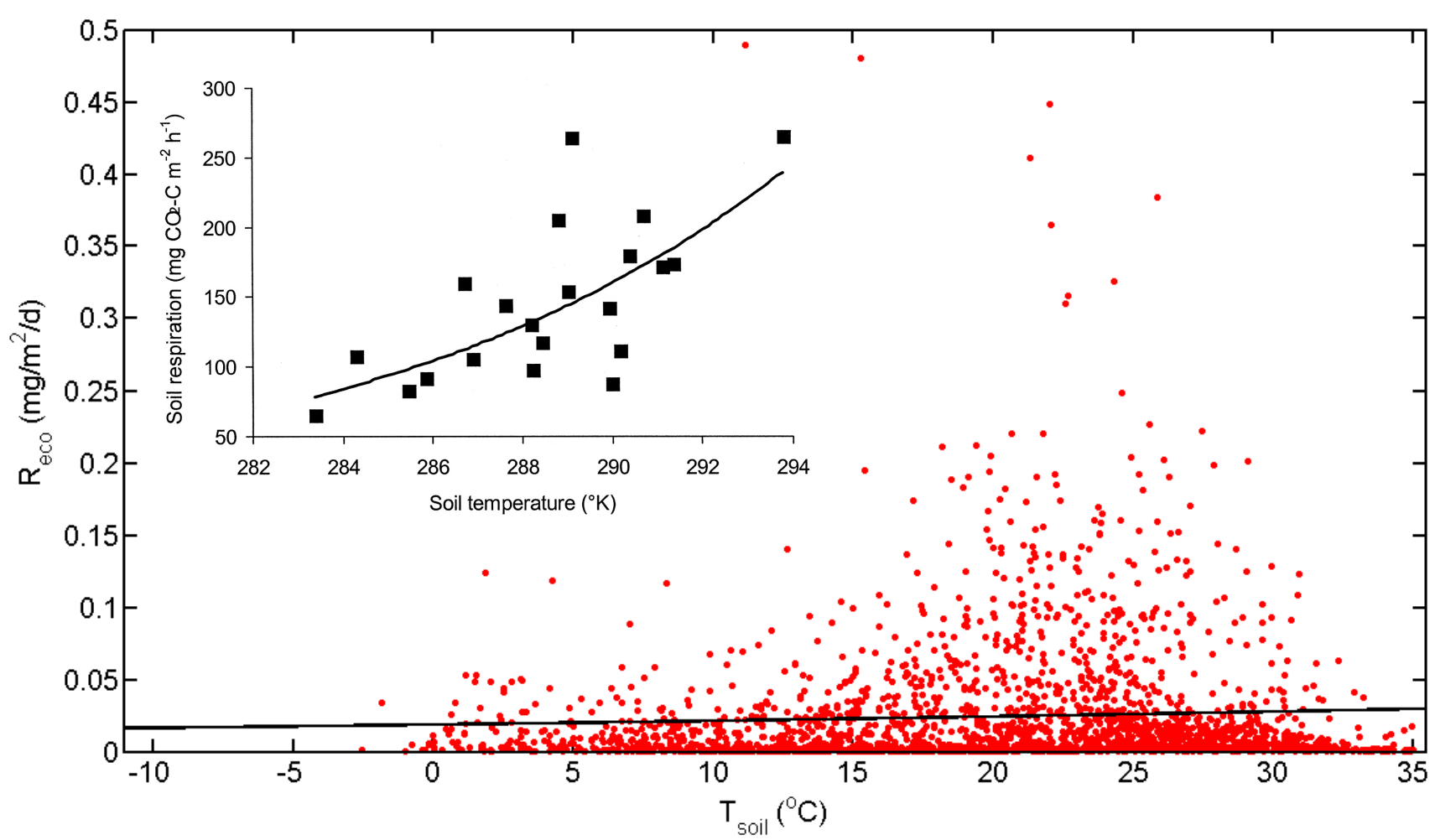
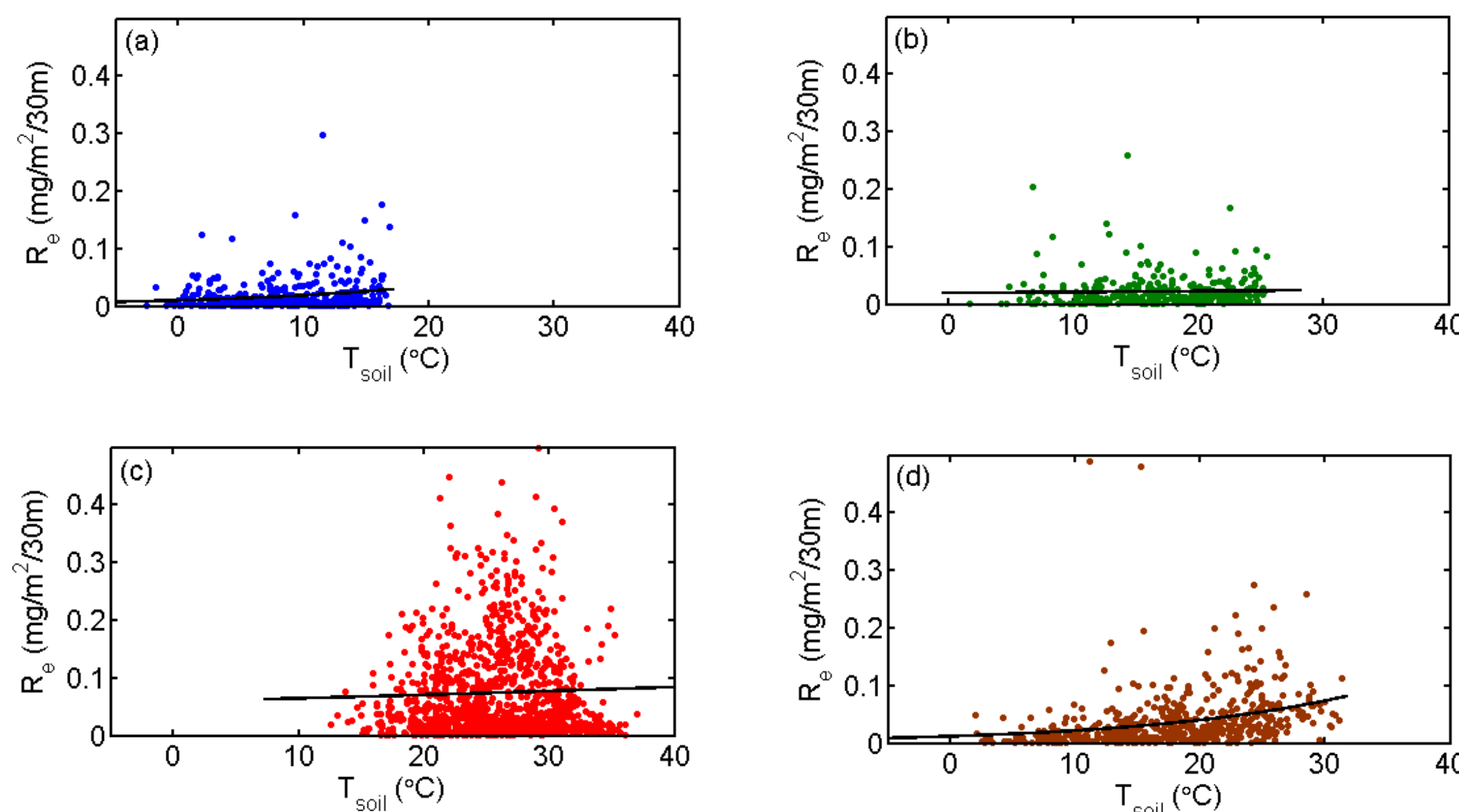For the entire dataset, an exponential relationship performs poorly, especially when compared to other ecosystems (inset, from Borken et al. 2003)
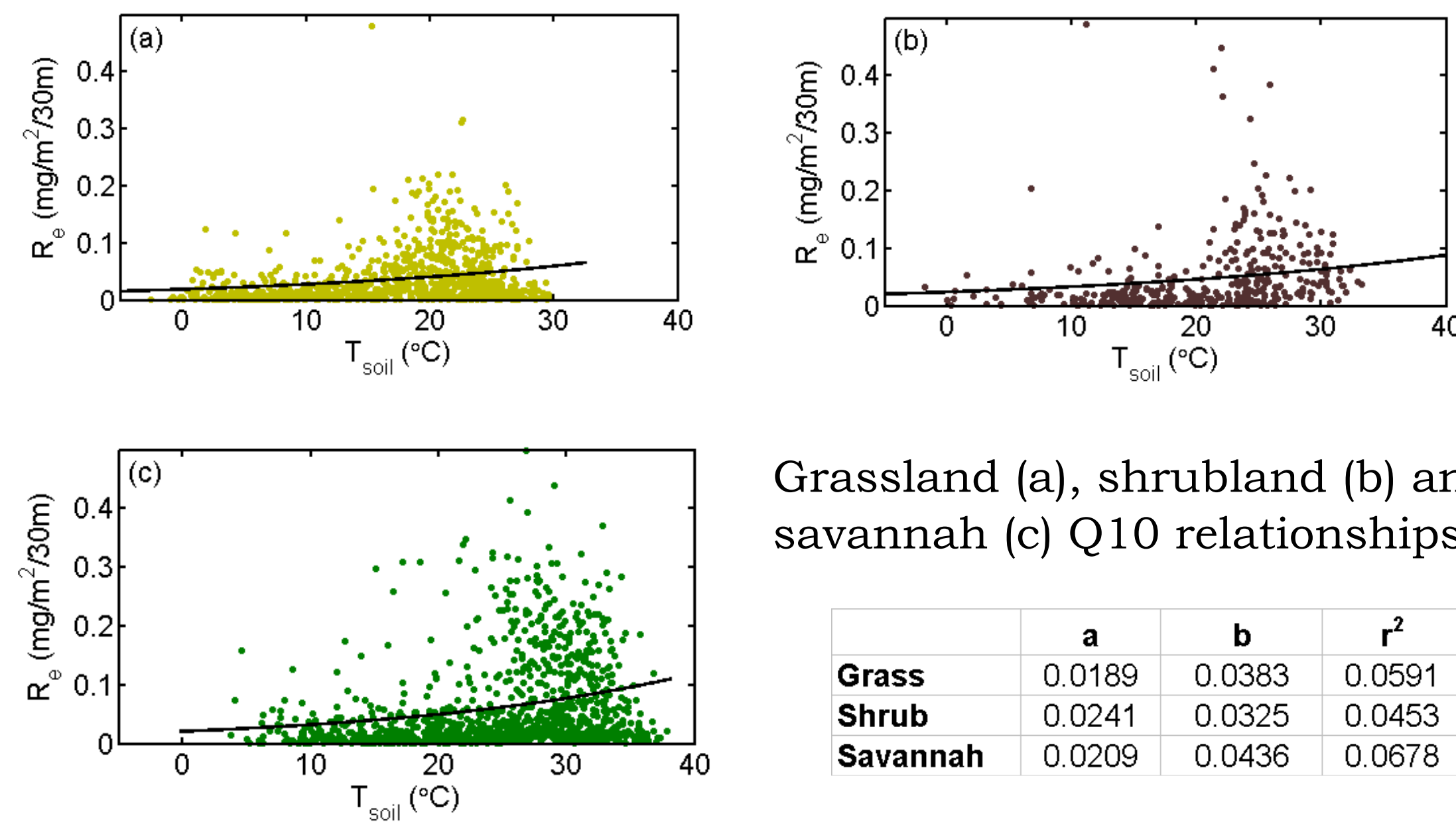
5. Categorical Variables

5.1 Season

	a	b	r2
Winter	0.0103	0.01614	0.0259
Spring	0.0197	0.0074	0.0008
Summer	0.0592	0.0089	0.0017
Fall	0.0121	0.0604	0.088

- Seasonal groupings explain little Reco-Tsoil variance
- Suggests that ecosystem respiration is not dependent on seasonal changes in productivity

Winter (a), spring (b), summer (c) and fall (d) Q10 relationships

5.2 Vegetation Type

Grassland (a), shrubland (b) and savannah (c) Q10 relationships.

	a	b	r²
Grass	0.0189	0.0383	0.0591
Shrub	0.0241	0.0325	0.0453
Savannah	0.0209	0.0436	0.0678

- No major improvement in model fit based on ecosystem type
  - R2 values are similar to seasonal categories
- Dynamic range of Reco in different communities
  - More frequent large respiration fluxes in savannah
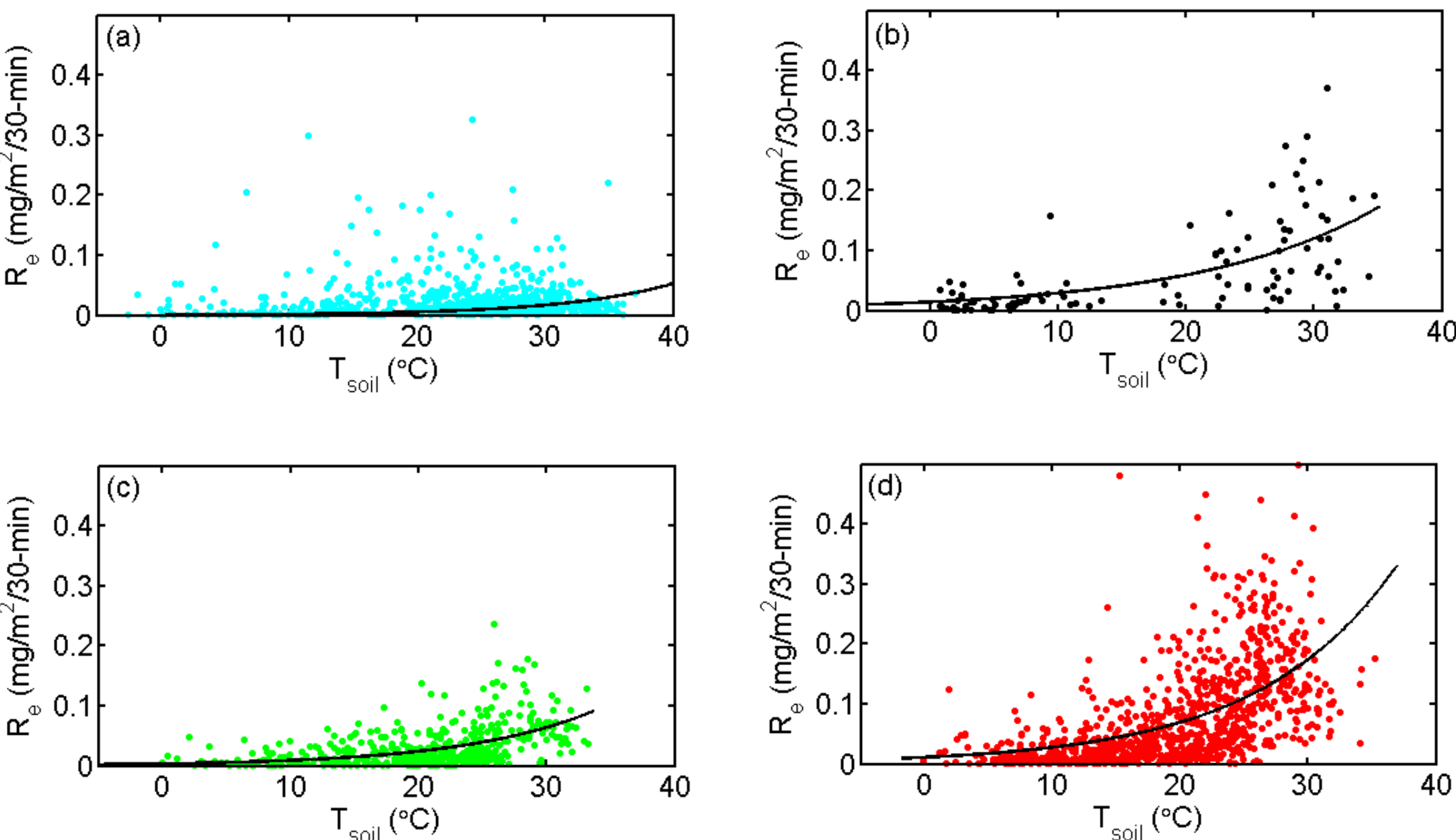 - Reco in grasslands limited at higher temperatures

Kendall Grassland

SRER Creosote (Shrubland)

SRER Mesquite (Savannah)

6. Soil Moisture

6.1 Reco-Soil Moisture
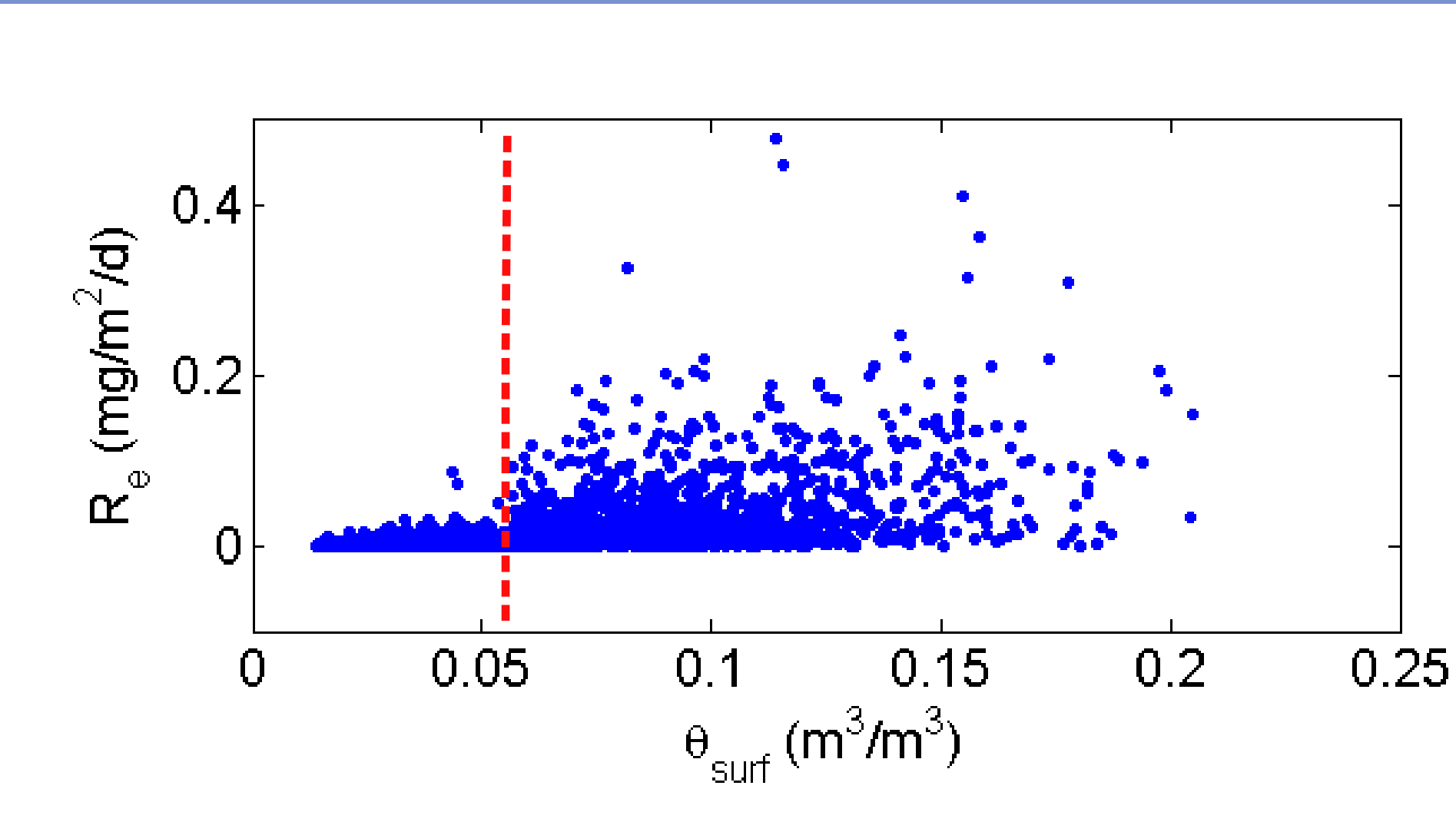
- Other studies use various model structures to relate soil moisture to Reco
- Note the threshold behavior of Reco as a function of θsurface
- Thus, a wet/dry threshold based on the vertical distribution of soil moisture may identify relationships in Reco

Case 1 (a), 2 (b), 3 (c) and 4 (d) Q10 relationships.

6.2 Soil Moisture Categories

Case 1   Case 3

Case 2   Case 4

- Expected respiration fluxes under moisture cases:
  - Case 1: autotrophic (maintenance) respiration
  - Case 2: heterotrophic decomposition and maintenance
  - Case 3: maintenance and growth respiration
  - Case 4: autotrophic and heterotrophic respiration

	a	b	r²
Case 1	0.0206	0.009	0.0034
Case 2	0.0144	0.0708	0.3839
Case 3	0.0035	0.0972	0.2574
Case 4	0.0111	0.0917	0.3373

- Q10-type model performs best based on soil moisture case
  - Best fit in Case 2
  - Similar fit in Cases 3 and 4
- Different parameter values for each case indicate different sensitivity to moisture source

7. Conclusions

The most effective respiration model found for semi-arid upland sites used inputs of soil temperature and soil moisture.

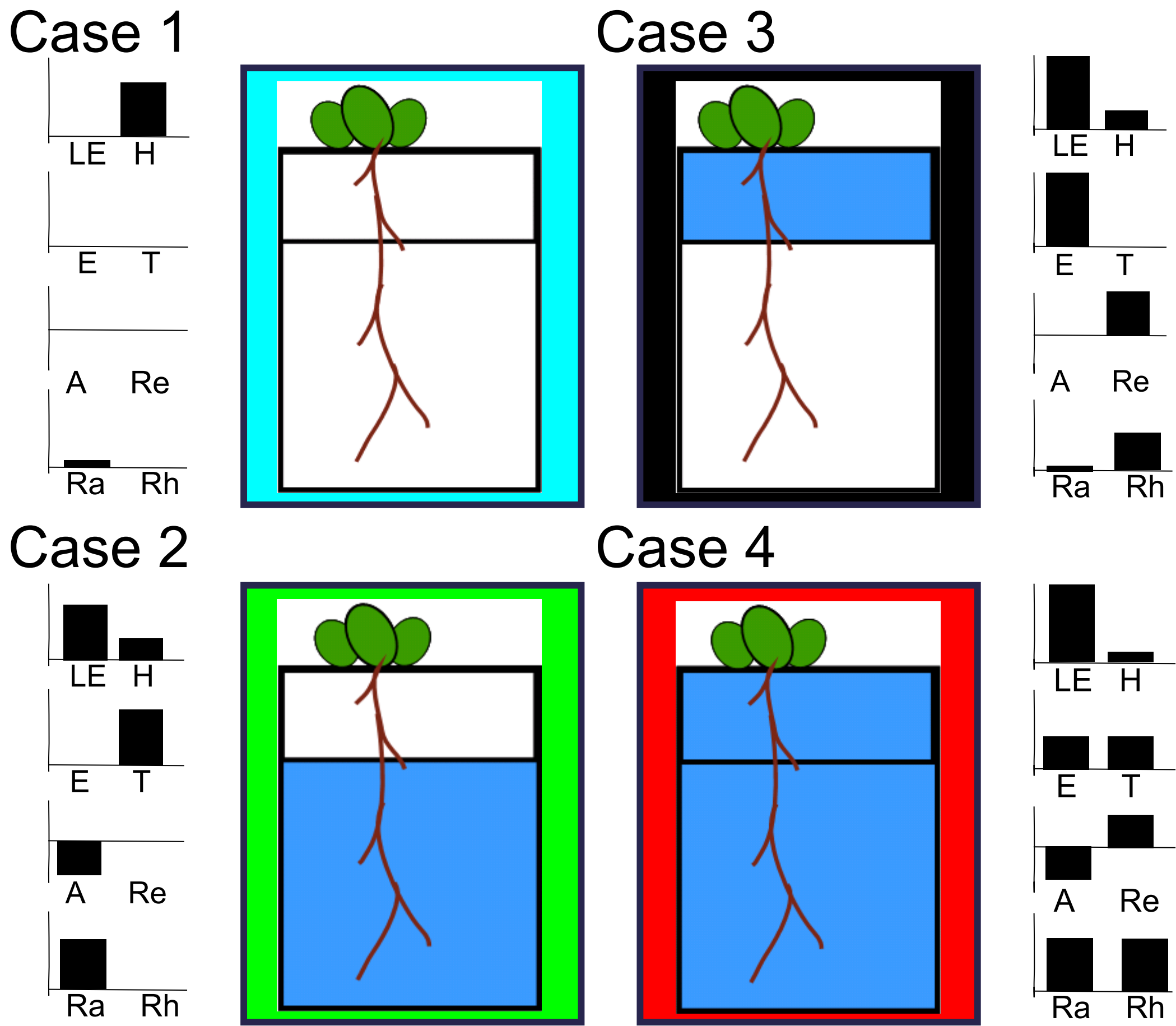Seasonality and vegetation type have little influence on ecosystem respiration in drylands.

Soil moisture acts as a threshold variable for respiration. Thresholds can be adequately identified via a two-zone soil moisture approach.

The two-zone soil moisture approach also leads to hypotheses about the source of respired carbon dioxide, from autotrophic and heterotrophic pathways (see Section 8).

References

Borken, W.; Davidson, E. A.; Savage, K.; Gaudinski, J.; Trumbore, S. E. (2003) Drying and Wetting Effects on Carbon Dioxide Release from Organic Horizons SSSAJ 67: 1888–1896.

Kurc, S.A.; Small, E.E. (2007) Soil moisture variations and ecosystem-scale fluxes of water and carbon in semiarid grassland and shrubland. *Water Resources Research.* 43(6) .

8. Future Work: Case 2 and Rh

To evaluate the hypothesis that the carbon flux in Case 2 is predominantly Reco, we compare results from nighttime and daytime fluxes.
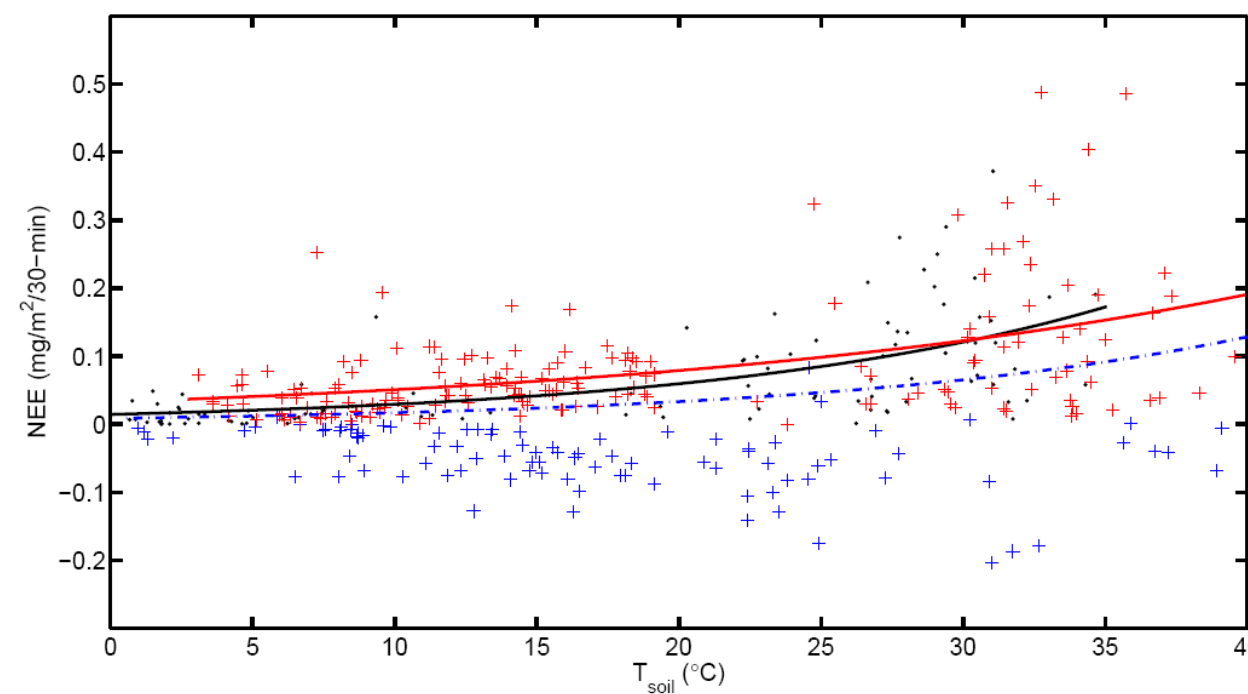
Overall, the nighttime (black dots) and daytime (red and blue crosses) models are not very similar (p = 0.11).
Removing the two grassland sites eliminates many of the instances of carbon uptake, and the new data (red crosses) has a trend similar to that of the nighttime data (p < 0.05).

Acknowledgements